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Study Of The Performances Of A Supply-Air Window For Air Renewal Pre-Heating

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Abstract

The principle of a supply-air window is based on the air renewal circulation between the glazings of a window before entering home. We study in this work the Paziaud® window composed of three glazings forming a U-shaped channel. The air warms up by recovering some part of the heat losses from the building and also by solar radiation absorbed through the glasses. This system generally works in forced convection by association with an air extraction system. This type of component is not embedded in usual dynamic tools for building thermal simulation. A major reason of this lack is that the heat transfers through the walls and the air exchange are treated separately. Moreover, this particular system is characterized by different heat fluxes if we consider the inner or the outer surface of the component. Our contribution is based on an original and appropriate representation of convective heat transfer in asymmetrically heated air layers. We offer a "simplified" model that can be easily implemented in dynamic simulation tools. This model is compared CFD simulations. From this model, parametric studies are performed to look for the parameters influencing the performance of the Paziaud® window: we show here that boundary conditions in temperatures, the thickness of the cavities, low emissivity coatings and the glazing area have significant effects on the performance criteria. We perform the parametric study on the basis of indicators specifically defined for the supply-air window.

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Keywords: Supply air window, Heat Recovery, Parametric studies, Simplified model

1. Introduction

The principle of a supply air window is to make the air renewal of the building circulating between the panes of glass of the window before entering into the building. A recent article [1] gives a complete study (literature review,

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numerical simulations and experimental work) on typical functioning of a supply-air window. We study here the window named Paziaud®. It is constituted of three panes of glass that delimit a U-shaped channel in which the air circulates [2]. The supply air warms-up by the heat loss of the dwelling and also by the solar radiation absorbed by the glass. Generally, the air circulates in this window by forced convection (with low velocity) associated with the extraction system of the building [3]. Two numerical models are used to carry out parametric studies in order to understand the influent factors on the thermal performance of a Paziaud® window: air flow rate in the window, temperature on both sides of the window, cavity thickness, low emissivity coatings, dimensions of the glazed surface. This parametric study, based on specific indicators defined for a supply air window [2–4] in paragraph 3, allows to show key points that will allow its future optimization.

2. Problem formulation

A laminar air flow is studied numerically entering through the upper section of a U-shaped ventilated window (Fig. 1) at the external temperature of 0°C. The air, being driven in forced convection, recovers a part of the thermal heat losses from the house (indoor temperature by default set at 20°C), and enters the room at an unknown temperature. The heat flux through the glazing « i » is Φ_i. The frame is not modelled in this study and the horizontal walls are supposed to be adiabatic.

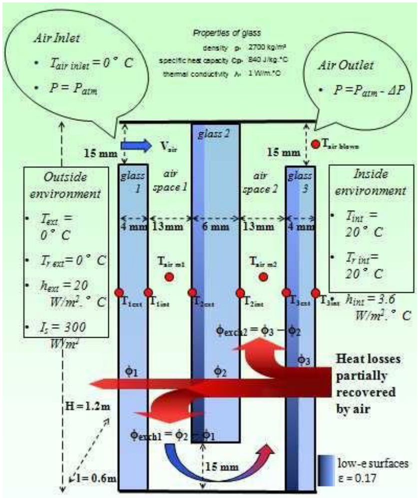

Fig. 1: Data and boundary conditions

Steady 2D numerical simulations are performed with the code Fluent® [3, 5]. Thermophysical properties of air are supposed to vary with temperature and the correlations used to determine them are taken from the standard EN 15099 [5]. A non-uniform structured mesh composed of 79 216 cells refined close to the glasses and close to the inlet and outlet of the channel is found to be sufficient for this study. Spatial discretization of the governing equations is achieved by means of the finite volume method using the pressure-based solver. The equations discretization was carried out using second order schemes for pressure and momentum (upwind scheme) and first order upwind schemes for energy and radiation. Momentum and pressure-based continuity equations are solved simultaneously with the coupled algorithm. To solve the long wave radiative transfer we use the Discrete Ordinates radiation model (DO). Convergence criteria were set at 10^{-6} for continuity, 10^{-7} for energy and 10^{-8} velocity and radiation. Concerning the boundary conditions for the external glazed surfaces (Fig. 1), two heat transfer coefficients are defined, h_{int} and h_{ext} corresponding to the indoor and outdoor environments. Radiative temperatures $T_{r\ int}$ and $T_{r\ ext}$ are defined at these side walls. The values of these parameters are defined in accordance with the ISO standard [5].

By default, glazings are 1.2 m high and 0.6 m width. The thickness of both air gaps is 13 mm. A low emissivity coating on glazings 2 and 3 is deposited towards the external part of the panes. The air change rate is set at 10 $m^3.h^{-1}$

in this study as an average value representative of the real conditions. To achieve the parametric studies, another numerical model called ABS (for Adapted to Building Simulation) was presented in a recent publication [2]; it was built in order to be easily inserted in building simulations codes. Its structure is simple and gives with a very satisfying accuracy the thermal performances of a ventilated window of any size and weather data. The main limit of this model is based on the hypothesis of forced convection inside the window.

3. Global performance indicators

Performance indicators have to be defined to energetically characterize a window. These indicators are explained in the international standard ISO-15099 [5]. The most commonly used are *U*-value and the solar heat gain coefficient τ_S (also called g in the standard EN 410). This solar heat gain coefficient is often replaced by the shading coefficient (SC) which is the ratio between (τ_S) and a reference corresponding to the solar heat gain factor of a simple clear 3 mm thick glass. These coefficients must be adapted to supply air windows, for which the choice of the reference heat flux has to be studied. Wright [4] defined an effective *U*-value called U_e (*1*) that can be used in the same test conditions than those of the standard considering the heat flux through the exterior pane of the window Φ_1. Another *U*-value can be used (U_{vent}) considering the heat flux through the interior pane of the window, Φ_3. In this case, it must be associated to a second performance indicator dependent on the supplied air (η_{vent}) [2].

$$U_e = \frac{\phi_1}{T_i - T_{ext}} \quad ; \quad U_{vent} = \frac{\phi_3}{T_i - T_{ext}} \quad ; \quad \eta_{vent} = \frac{T_{airsoufflage} - T_{ext}}{T_i - T_{ext}} \qquad (1)\#$$

These indicators can be considered as the characteristics of a system equivalent to a common window with a *U*-value (U_{vent}) added to a heat recovery system on extracted air with a performance indicator η_{vent}.

This model is not suitable for windows with large cavities in which the effects of buoyancy forces cannot be neglected (mixed convection). The results presented in paragraphs 6, 7 and 8 come from this model, whereas those of paragraph 4 and 5 are from the code Fluent®.

4. Influence of the air flow rate in the window

One can note (Fig. 2) that the thermal performances of the window increase with the air flow rate. It is true considering the heat loss across the window (U_e decreases) but also in terms of solar gains recovering (τ_S increases).

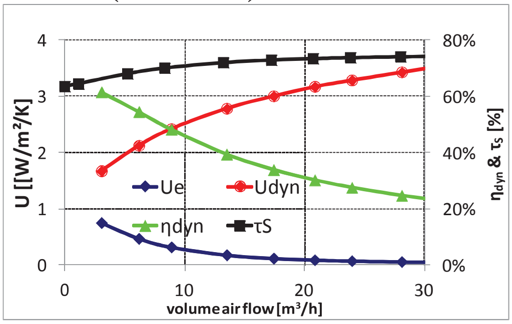

Fig. 2: performance criteria as a function of air flowrate

This phenomenon can be explained by the fact that when the air flow rate increases, the heat flow rates between the glasses inside the window are almost reduced to radiative transfers. The almost entire conductive heat flux of the glass is carried away by the air flow and then re-injected into the room. Furthermore, one can see that the solar gain is close to the one of a simple glass because almost the entire solar radiation absorbed by the central glass is also recovered by the air flow. As a result, the window has the advantages of a triple glazing concerning the heat loss and the advantages of a simple glass for solar radiation heat recovery. The increase of the air flow rate leads to a decrease of the internal surface temperature that has to be limited for thermal comfort.

5. Influence of the indoor and outdoor temperatures

Considering the operating principle of the supply air window, it is important to verify whether the performance criteria are or not independent on environmental conditions at both sides of the window. It is known that for a conventional window, the performance depends on the temperature [6] due to the variation of the heat transfer coefficients. Nevertheless, insofar as it varies slightly, it is widely agreed that the performance indicators may be considered as independent on temperature. This study proposes to identify the influence of the indoor and outdoor temperatures on the performances of the supply air window for a given air flow rate (Table 1) using the CFD model.

Table 1: influence of indoor and outdoor temperatures on thermal performances of the window

$T_{int} - T_{ext}$ (°C)	T_{ext} (°C)	T_{int} (°C)	Inlet volume air flow ($m^3.h^{-1}$)	Mass air flow ($kg.s^{-1}$)	Characteristic parameters of the window		
					U_e ($W.m^{-2}.°C^{-1}$)	U_{vent} ($W.m^{-2}.°C^{-1}$)	η_{vent}
40	-20			0,00362	0,22	2,52	0,46
30	-10			0,00354	0,25	2,51	0,48
20	0	20		0,00347	0,28	2,51	0,46
10	10			0,00341	0,31	2,50	0,46
5	15		10	0,00338	0,33	2,50	0,46
-5	25			0,00332	0,37	2,50	0,47
-5	30			0,00326	0,39	2,53	0,47
-10	35	25		0,00323	0,41	2,53	0,47
-15	40			0,00321	0,43	2,53	0,48

It is first noted that the temperature variations have a significant effect on the mass flow rate, which can explain the change in the performance indicators. The U_{vent} and η_{vent} coefficients seem almost constant for any outdoor and indoor temperatures. That is not the case for the U_e parameter increasing with the air temperature. Consequently, it is more interesting to use the U_{vent} and η_{vent} criteria to model the ventilated window in a global building simulation because these parameters are less dependent on the indoor and outdoor temperatures when the airflow rate is imposed.

6. Influence of air spaces thickness

In this study we also propose to identify the influence of the thickness of the air spaces on the performance criteria. This study is conducted with the ABS model with an assumption of forced convection. Preliminary simulations carried out with Fluent® have shown that this is valid when the thickness of the second cavity is less than 20 mm. Beyond this value, it appears a downward flow along the coldest wall so that the convection can no longer be considered as forced convection. In this parametric study, the window configurations are set not to have dual circulation. The thickness of the first cavity varies from 10 mm to 30 mm and the one of the second cavity from 10 mm to 20 mm. The results (

Table 2) lead to the following conclusions:

- Increasing the thickness of the first cavity generates a decrease in the parameter U_e.
- Increasing the second cavity thickness yields a decrease of the U_e coefficient. The window is therefore more efficient.
- U_e parameter is minimal when the two air spaces have a similar thickness for a given air volume in the window.
- Increasing the air flow rate in the window causes a decrease of U_e for similar cavity thicknesses.

From an energy point of view, lower the U_e coefficient is obtained better is the performance of the window. In this context, a high air flow rate in the window should be imposed with equivalent cavity thicknesses. In addition, further study is needed to examine the influence of the phenomenon of dual circulation on the performance criteria.

Table 2: influence of air spaces thickness (ABS model (air flow rate: 8,9 $m^3.h^{-1}$)

Air gap thickness		Performance criteria		
e_1 (mm)	e_2 (mm)	U_e $W.m^{-2}.°C^{-1}$	U_{vent} $W.m^{-2}.°C^{-1}$	η_{vent}
10	10	0,48	2,55	0,47
10	20	0,31	2,13	0,41
13	13	0,35	2,38	0,46
15	15	0,30	2,28	0,45
20	10	0,33	2,50	0,49
20	20	0,22	2,10	0,43
30	10	0,28	2,48	0,50
30	20	0,18	2,09	0,44

7. Influence of glass surface dimensions

A sensitivity study is carried out on glazing surface dimensions thanks to the ABS model. We can see (Fig.3) that the aspect ratio (ratio between glass height "H" and its width "W") has no influence on performance criteria (Fig. 3a). Three-dimensional geometry should be considered to ensure that this conclusion is definitely valid and increasing the glass surface at fixed air flow rate goes with an increase of parameters U_e and η_{vent} and a decrease of parameter U_{vent} (Fig. 3b). These results are consistent with those of the literature [7]. For constant air flow rate, the increase of glass surface increases the time during air is effectively into the window. The entire window becomes in average warmer. Thermal heat losses and air preheating are larger whereas heat flux transferred between the inside and the window is reduced. Therefore, if for thermal comfort, a higher blowing temperature and a higher internal surface are required, global performances of the system decrease (and vice versa).

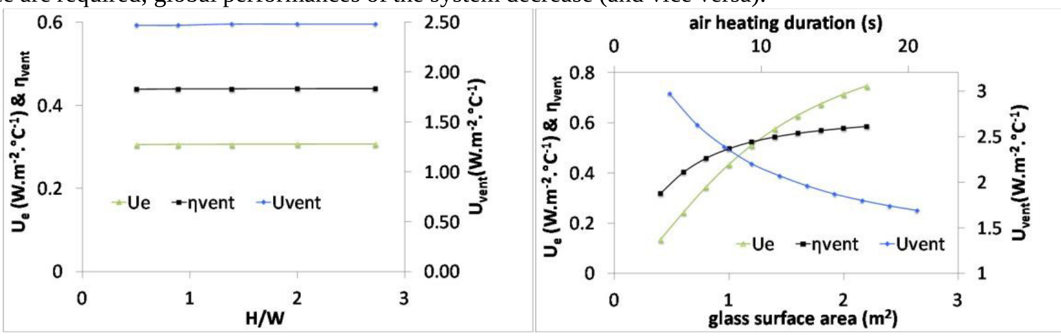

Fig. 3: (volume air flow fixed to 10 $m^3.h^{-1}$) - (a) variation of H/W ratio with constant area - 0.72 m² (b) variation of glass area

8. Influence of low emissivity coatings

We identify here the advantage to equip the windows with low emissivity glazing. Four configurations are tested to study the influence of the coating position (see Table 3).

Table 3: Optical properties and average radiative exchange coefficients for each studied device

Disposal	a	b	c	d

glass 2 emissivity - ext face	0,17	0,84	0,17	0,84
glass 3 emissivity - ext face	0,17	0,17	0,84	0,84
Radiative exchange coefficient in the air layer n°1 h_{r1} ($W.m^{-2}.°C^{-1}$)	0,79	3,34	0,79	3,40
Radiative exchange coefficient in the air layer n°2 h_{r2} ($W.m^{-2}.°C^{-1}$)	0,84	0,84	3,72	3,72

For this study, we use the linearized radiative coefficients h_{r1} h_{r2} calculated with the different emissivity values for each air layer. First, we can note that the radiation exchange coefficients between two glasses are reduced to a significant degree when low emissivity coating is present (Table 3). As expected, the case (a) is the one that most reduces the IR radiation heat transfer. It provides optimum performance. g and η_{vent} parameters are not very sensitive to the presence of low-emissivity coatings; however, the presence of this type of coating in the first air layer appears to improve them slightly. Regarding U_e coefficient, the more there is low emissivity coatings in the window, the more the radiation exchanges are reduced and become weak. For the U_{vent} parameter, it is mainly the low emissivity coating of the second air layer which reduces the value.

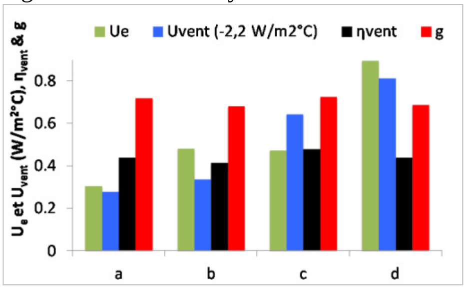

Fig. 4: Influence of low emissivity coatings on the performance criteria from the ABS model

9. Conclusion

The air flow rate is the main parameter conditioning device performances. It is observed that higher the air flow rate in the window is, more efficient the window is. Note that this result is true only for the window. At the scale of the building, after a time, if too much air comes through the windows (more than needed) the overall system performance will inevitably fall.

- The ambient and climatic conditions on each side of the window have an effect on the performance criteria. This study highlighted the interest of using the coefficients U_{vent} and η_{vent} defined in [2] because they remain almost constant when the air flow rate changes.
- Air layers thicknesses: it is necessary that the thickness of the second air layer (indoor side) remains relatively small so that no descending flow appears on the cold wall. A limit thickness value of 20 mm was identified here.
- Low-emissivity coatings improve the device performances (~ factor 2 on the global heat loss coefficient).
- The size of the window (area) has a significant impact on the performance criteria because the time during which the air is effectively in the window is changed at constant air flow.

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